National Aeronautics and Space Administration

Thermally Managed Battery Cases for Cold Environments

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Objectives

The objective was to design a battery case for lunar night (adaptable to deep space, icy moon landers, or outer planet exploration), integrating a singly located RHU cluster capable of thermally managing the entire system at cryogenic temperatures while thermally decoupling during the lunar day.

Background

Lithium-ion batteries have superior low temperature performance compared to aqueous chemistries. Yet, even the best low temperature Li-ion batteries developed at JPL can only operate down to -60°C, and the energy delivered by the battery drops off sharply with temperature, due to slow reaction kinetics at low temperatures. A more efficient solution would be to heat the battery to a temperature >0C to be able to realize its energy fully. Thus, there needs to be a tradeoff between improving the innate low temperature performance of the battery versus providing heat either externally or from its own energy. For more extreme temperatures and durations, as during lunar night, a battery doesn't provide enough energy to keep itself warm and will require an external heater. Radioisotope heater units (RHU) are the mass and volume efficient solutions to provide heat and were used successfully on Mars Exploration rover batteries. However, RHUs offer very concentrated sources of heat, which, when used with a traditional low thermal conductivity case, cause large thermal gradients. This results in many RHUs needing to be scattered around the battery case, increasing mass, volume, cost, and additional work required to integrate Plutonium-238 RHUs unattractive.

Approach and Results

To mitigate the effects of small, high power heat sources, we need elegant approaches to redistribute the heat efficiently throughout the battery, especially at the extreme low-temperature's during lunar night. Zeno Power Systems has been developing an alternative Strontium-90 based RHU system with slightly lower power density than Pu-based systems. Undoubtedly, RHUs are great at keeping warm during the lunar night, but during the day their additional heat becomes a burden, by heating the spacecraft when cooling is the process needed. At this point, they need to be thermally decoupled or require a larger radiator.

Recently, JPL has developed a battery case with integrated thermal management capable of preventing a cascading failure in a Li-Ion system through its extraordinarily high thermal conductivity. It is also exceptional at managing heat generated during high charge and discharge rates, unlike other cases capable of mitigating thermal runaway. This case can also be used to distribute heat from a remotely located thermal source, if one was provided.
The bulk of the work in this project consisted of thermal models and brainstorming for novel heat pipe geometries. A coarse radiative thermal model for a 500 kg rover in the PSR was developed by Michael Cox. The goal was to understand the needed watts to provide adequate heating for a box of fixed internal volume, but various aspect ratios. Figure 1 shows the results for an applied power of 65 W. As can be seen, the greater the fraction of sky view, the colder the box will get. The warmest geometry is akin to a thin vertical rod; as very little surface will be directly facing the sky.

The project also developed a novel architecture for creating a system to automatically thermally disconnect the radiator from a heated electronics box when entering a cold environment. It is called a Variable Conductance Thermosyphon (VCT), and is outlined in Figure 2. The VCT is arranged with a heat source (ie, RHU), heat user (batteries), and heat sink (radiator) to provide reliable temperature control for all operating scenarios in the lunar environment (night, day, PSR regions). It can provide adequate thermal control of supplemental components (batteries/avionics) no matter if the system is exposed to the lunar day and operating the batteries, or if it is shadowed and trying to conserve energy.

Due to time constraints and other activities, not all of the proposed objectives were able to be delivered. We did not perform studies for alternative high temperature battery systems to eliminate the need for a radiator, and we were not able to complete a full resolution model of a battery case to understand the thermal needs of it alone with an 18650 cell replaced with a drop-in RHU.

Significance/Benefits to JPL and NASA

This work led to a NASA Game Changing Development proposal partnered with Zeno Power Systems. In it, JPL would use their expertise in designing and additively manufacturing heat pipes systems to thermally manage Zeno's Sr90-RHUs to distribute their heat during the lunar night, while thermally isolating them during the lunar day.

The project also directly impacted a Strategic R&TD proposal to develop a lunar rover for the permanently shadowed regions.

For the long term, this project gave insight into the ability of JPL's thermally managed battery cases to sustain a mission in extreme thermal environments. It showed the capability of exceeding the current state of the art in maintaining isothermality during operation, a benefit of interest to projects such as Europa Lander.

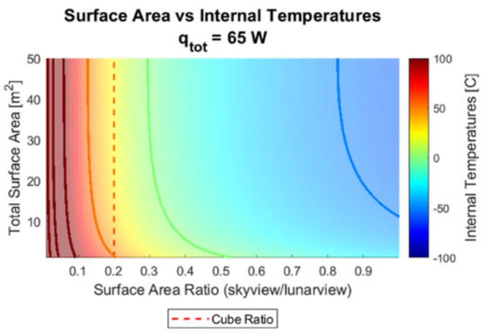

Figure 1 – A 2d plot of internal temperature for a variety of box aspect ratios and surface areas given an internal heat source of 65 W.

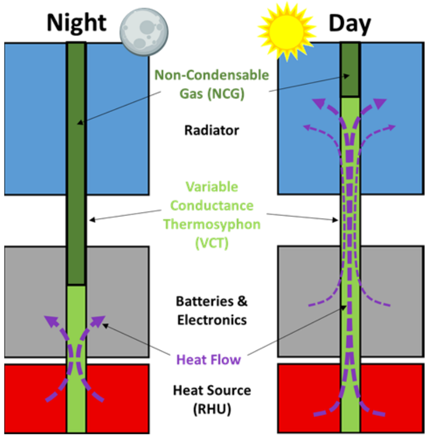

Figure 2 – Schematic architecture for a Variable Conductance Thermosyphon (VCT)

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Publications

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